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SOIL INGESTION - A MAJOR PATHWAY OF HEAVY METALS INTO LIVESTOCK GRAZING CONTAMINATED LAND

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ABSTRACT

An estimated 4000 km^2 of agricultural land in England and Wales has been contaminated in varying degrees by past mining and smelting activities. Contaminants include one or more of the metals Cu, Pb, Zn, Cd and As. Studies conducted in southwest and central England conclude that only a small proportion of these metals are taken up into the leaf material of pasture plants and that plant uptake would not seem to constitute a major pathway to grazing animals. Using the titanium content of faeces as a stable indicator of soil ingestion, we found that grazing cattle involuntarily ingest from 1% to nearly 18% of their dry matter intake as soil; sheep may ingest up to 30%. Soil ingestion varies seasonally and with farm management. Calculations based on soil, plant and faecal analyses show that from 9% to 80% percent of the Pb and 34% to 90% of the As intake into cattle on contaminated land is due to ingested soil.

INTRODUCTION

Grazing animals involuntarily ingest soil along with grass. Previous work in Britain and New Zealand has shown that cattle may ingest from 1% to over 10% of their dry matter intake in the form of soil, and up to 30% or more in sheep that graze closer to the ground [1-6]. The role of soil ingestion is thought to be of particular importance as a pathway of metals into the animals in areas where soils are contaminated with or contain naturally high concentrations of heavy metals. In addition ingested soil may be important as a source of nutrients, possibly providing beneficial quantities of cobalt, copper, selenium and zinc [2,7]. It has been reported that under experimental conditions in Tasmania, sheep

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grazing in pastures on light sandy soil had more goitrous lambs than those on a clay soil; it was suggested that the iodine supply to sheep on the clay could be supplemented as a result of soil ingestion [8]. Conversely, it has been shown under experimental conditions that when hypocupraemic sheep were fed soil, at 10% of the dry matter intake, with a Cu-supplemented diet, the soil reduced the availability of dietary Cu by more than 50%. This suggested that either the soil was occluding Cu in the alimentary tract, or releasing a copper antagonist [5]. The amount of soil ingested will depend on the type of pasture, management, soil type, season and weather factors such as rainfall [9]. For example, the intensity of rainfall, type of sward and soil texture, together with the presence or absence of an organic matt at the soil surface, will affect the amount of soil splash onto the surface of leaf material. Soil ingestion is almost certainly largest when grass is in short supply, in the winter months and in very dry summers.

As a result of geochemical mapping and associated soil sampling programs, it has been estimated that ~4000 km^2 of agricultural land in Britain has been contaminated by metals in varying degrees as a result of past mining and smelting activities [10,11]. This paper presents the results of two investigations into soil ingestion by cattle in historical mining and smelting areas in Derbyshire and Cornwall. In the former, soils over an area of ~250 km^2 are contaminated with varying amounts of Pb, Zn and Cd, with concentrations of Pb varying from several hundred to several thousand mg kg^{-1} and up to 1% (w/w) near old workings and smelter sites [12]. In the Hayle/Camborne area of Cornwall, agricultural soils range up to 2000 mg kg^{-1} As and 1000 mg kg^{-1} Cu and the contaminated area associated with Cu-(Sn)-As mineralization, mining and smelting is approximately 800 km^2 [13].

MATERIALS AND METHODS

Sampling and Analysis

In Derbyshire, eleven farms were sampled in 1976, each carrying dairy units or beef or single suckler herds. These were selected on the basis of earlier work [12] to provide soils ranging from 100 to 4000 mg kg^{-1} Pb.

Surface soils (0-15 cm), comprising 20 subsamples bulked from each field grazed, were oven-dried at 80°C and the <2mm fraction ground to pass 200 µm mesh for the analysis of Pb, Zn and Cu by atomic absorption spectrophotometry (AAS) after digestion in concentrated nitric and perchloric acids. Composite herbage and faeces samples (20 subsamples bulked) were taken monthly throughout the grazing season (April to November); herbage was cut to 2.5 cm above the soil to avoid contamination, and faeces taken from the surface of recently deposited material taking care to avoid soil. Both herbage (unwashed) and faeces were dried at 80°C, ground in a hammer mill and analyzed by AAS. Titanium in soil and faeces was determined colorimetrically after digesting ignited samples in a mixture of nitric perchloric and hydrofluoric acids.

In Cornwall, studies were commenced on eleven farms in 1979 involving the sampling of soil, herbage and faeces in spring, early and late summer. Methods of sampling and analysis were the same as those for the Derbyshire farms. In addition, arsenic was determined by inductively coupled plasma emission spectrometry (ICP) after reduction to arsine by sodium tetrahydroborate [14].

Calculation of Soil Ingestion

In this study the titanium content of faeces has been used as a stable marker of soil ingestion. Titanium is present in relatively high concentrations in soils (several thousand mg kg^{-1}) and in very small amounts in herbage (usually less than 10 mg kg^{-1}). Soil ingestion has been calculated, assuming a digestibility of 70% and a dietary intake of 13.6 kg per day, using the equation:

$$\%\ \text{soil ingestion} = \frac{(1 - Dh)\ Ti_f}{Ti_s - DhTi_f} \times 100$$

where Dh = digestibility of herbage

Ti_s = titanium in soil

Ti_f = titanium in faeces

RESULTS AND DISCUSSION

Derbyshire

In the early summer (May), the amount of soil ingested by cattle was similar on each of the eleven farms studied, ranging from 2.1% to 4.4% of the total dry matter intake. These levels are consistent with a time of year when there was a rapid growth of pasture and this fresh material, by the very nature of its height, is subject to relatively little soil splash. The total daily intake of both Pb and Zn increased with soil metal content (Table 1), as did faecal metal content. Levels of Cu in these soils fall within the normal background range. Parallel studies conducted on the same farms showed that in May there was little difference in the lead content of grass (measured on a dry weight basis) growing in soils of widely differing lead contents [15, Fig. 1]. This probably reflects the barrier to lead uptake at both the soil:root and root:shoot interfaces [16]. Concentrations of Pb in unwashed herbage dry matter rise markedly during the winter months, in part due to soil contamination, and may well increase Pb intake into grazing sheep.

The contribution of soil to the total Pb intake of cattle ranged from 9% to over 80% and on most of the farms exceeded 40%. The contribution of soil to Zn and Cu intake was less, ranging from 3% to 36% and 5% to 11% respectively. Thus, it would seem that over the range of soils/farms tested, Pb ingested as soil makes a major contribution to the total intake of cattle, while plant uptake is the main pathway for Zn and Cu. The general relationship between blood lead values and those in soils on these farms has been reported previously, with approximately 10 ug Pb/100 ml blood on the 'low lead' farms and 30 ug Pg/100 ml on the 'high lead' land [15]. This would seem to indicate that part of the Pb ingested as soil is bio-available.

TABLE 1.

Mean contribution of soil to total daily intake of Pb, Zn and Cu in eleven herds of cattle in Derbyshire, England.

Farm type (based on soil Pb)	Mean % soil ingested	Soil content $mg\ kg^{-1}$			Total daily intake mg/day			% element ingested as soil		
		Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn	Cu
100-500 mg kg^{-1} Pb n=4	2.9	276	87	19	289	590	134	40	6	6
600-1000 mg kg^{-1} Pb n=4	3.7	856	311	37	621	860	170	71	19	11
1000-4000 mg kg^{-1} Pb n=3	2.9	2942	287	39	1700	714	152	66	15	9

TABLE 2.

Mean contribution of soil to total daily intake of As and Cu in eleven herds of Cattle in Cornwall, England.

Farm type (based on soil As)	Mean % soil ingested	Soil $mg\ kg^{-1}$		Faeces $mg\ kg^{-1}$		Total daily intake mg/day		% element ingested as soil	
		As	Cu	As	Cu	As	Cu	As	Cu
20-40 $mg\ kg^{-1}$ As n=3	1.4	24	26	1.3	32	7	140	67	4
55-140 $mg\ kg^{-1}$ As n=3	1.4	85	93	3.1	46	21	175	76	10
160-250 $mg\ kg^{-1}$ As n=5	1.1	202	199	8.1	51	52	190	58	16

Cornwall

In June, soil ingestion by cattle was low on all eleven farms tested, not exceeding 2% of the total dry matter intake (Table 2). When the farms are grouped into three classes based on soil As content, both total intake and faecal contents of As and Cu increased with soil contents. Total intake of As ranged from 7 mg/day on the low arsenic soils to 52 mg/day on the high arsenic soils (Table 2). Total intake of Cu reflected the soil content to a lesser degree. The contribution of soil to the intake of As was large, exceeding 58% in each of the three groups of farms; less Cu was ingested as soil, not exceeding 16% of the total intake.

On most of the farms studied, ingestion of soil was highest (up to 18%) in the early spring (April) when grass was in short supply. In early summer (June) soil ingestion had fallen below 2%, rising again in late summer (August). As illustrated by the data from the three farms shown in Table 3, throughout the season both the soil As content and the amount of soil ingested markedly influenced the total As intake and the faecal As content. Soil ingestion accounted for 34% to 90% of the As intake, which varied appreciably from 4 to 15 mg/day in early summer to as much as 215 mg/day on one farm in spring. From 2% to 63% of the Cu intake was due to soil, the larger amounts on mine-contaminated land in the spring, when ~50% to 60% of Cu intake was that in soil, compared with 2% to 3% in early summer when little soil was ingested. Total Cu intake ranged from ~150 mg/day in early summer up to 300 mg/day in spring, a much smaller percentage variation than that for As.

TABLE 3.

Seasonal differences in daily intakes of As and Cu by cattle on three farms with low, medium and high soil As and Cu.

Farm type (based on soil As)	Mean % soil ingested	Soil mg kg^{-1} As	Soil mg kg^{-1} Cu	Unwashed herbage mg kg^{-1} D.M. As	Unwashed herbage mg kg^{-1} D.M. Cu	Faeces mg kg^{-1} D.M. As	Faeces mg kg^{-1} D.M. Cu	Daily intake as soil mg/day As	Daily intake as soil mg/day Cu	Daily intake as herbage mg/day As	Daily intake as herbage mg/day Cu	Total daily intake mg/day As	Total daily intake mg/day Cu	% element ingested as soil As	% element ingested as soil Cu
Low As															
April	2.7			0.5	12	1.5	28	9	11	6	165	15	176	60	6
June	0.6	25	29	0.1	11	0.9	38	2	2	2	149	4	151	56	2
August	2.6			0.5	9	1.6	24	9	10	7	126	16	136	56	7
Medium As															
April	17.9			1.3	13	31.1	39	136	156	15	145	151	301	90	52
June	0.6	56	64	0.2	11	1.8	31	5	5	3	149	8	154	60	3
August	3.2			0.4	11	2.3	32	29	28	6	145	35	173	83	16
High As															
April	7.2			2.3	14	19.5	64	187	121	28	177	215	298	87	63
June	0.2	191	124	0.7	10	0.9	55	5	3	10	136	15	139	34	2
August	3.9			1.5	8	10.3	40	101	66	19	105	120	171	84	39

CONCLUSIONS

Ingested soil is clearly an important pathway in the two areas studied of Pb and As respectively into grazing cattle, and faecal contents of the two metals provide an indication of intake. This is of particular importance on contaminated land or on land with a naturally high metal content, where as a result of soil ingestion, metal intakes can be large. Total daily intake of these two elements is thus related to both soil content and the amount of soil ingested. It is likely that this conclusion will apply to other metals/trace elements present in the soil in relatively large concentrations but in pasture herbage in much lower concentrations. Thus, ingested soil is potentially an important source of both toxic and essential elements to the grazing animal.

As yet little is known about the chemical forms and species of heavy metals and trace elements in either soil or pasture herbage. These forms will almost certainly govern the amount available for release and absorption in the alimentary tract of the animal. As shown in the two studies reported, much of the elements ingested as soil are removed from the animal in the faecal material and are not available for metabolic/antagonistic effects. In Derbyshire, for instance, clinical Pb poisoning in cattle and sheep is rare and usually involves animals straying on to actual mine spoil. It is possible, however, that subclinical effects may be present and likely that liver and kidney tissue will accumulate Pb.

Sheep grazing in winter months will be exposed to herbage containing raised lead levels, which together with high rates of soil ingestion at times of grass shortage, may present a hazard.

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